Comparison between high-field 3 Tesla MRI and computed tomography with and without arthrography for visualization of canine carpal ligaments: a cadaveric study

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Abstract: OBJECTIVE:To compare the quality of visualization of canine carpal ligaments by using computed tomography (CT), MRI, CT arthrography (CTA), and magnetic resonance arthrography (MRA). STUDY DESIGN: Prospective descriptive study. STUDY POPULATION: Cadavers from dogs weighing more than 20 kg. METHODS: A 16-slice CT scanner and a 3 Tesla MRI were used for the investigation. A dilute contrast medium was injected into the middle carpal and radiocarpal joints under fluoroscopic control, and CTA and MRA images were acquired. To evaluate the difference between imaging modalities, 3 observers graded carpal ligaments of clinical interest using a scale from 0 to 4 for their quality of visualization. Data were analyzed by using a random-effect ordinal logistic regression with Bonferroni adjustment. The interobserver agreement was calculated by using the weighted Cohen's κ. RESULTS: Normal carpal joints (n = 9) were investigated. Magnetic resonance arthrography improved visualization of the majority of carpal ligaments compared with MRI ($P < .05$) and offered the best visualization overall. Magnetic resonance imaging and MRA offered better visualization compared with both CT and CTA ($P < .05$). There was no difference between CT and CTA. Interobserver agreement was discrete ($0.2 < \kappa \leq 0.4$) for all observers. CONCLUSION: Arthrography improved the capabilities of MRI but not of CT for visualization of the canine carpal ligaments. Magnetic resonance arthrography was particularly useful for evaluation of the stabilizers of the antebrachiocarpal joint. CLINICAL SIGNIFICANCE: 3 Tesla MRA and MRI allow excellent visualization of the ligamentous morphology and may be helpful in the diagnostic process of carpal sprains in dogs.

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ABSTRACT

OBJECTIVES: To compare the quality of visualization of canine carpal ligaments using CT, MRI, Computed Tomography Arthrography (CTA), and Magnetic Resonance Arthrography (MRA).

STUDY DESIGN: Prospective descriptive study.

ANIMALS: Cadavers from dogs weighing more than 20 kg.

METHODS: A16-slice CT scanner and a 3 Tesla MRI were used for the investigation. A dilute contrast medium was injected into the middle carpal and radiocarpal joints under fluoroscopic control and CTA and MRA images were acquired. To evaluate the difference between imaging modalities, three observers graded carpal ligaments of clinical interest using a scale from 0 to 4 for their quality of visualization. Data were analyzed using a random effect ordinal logistic regression with Bonferroni adjustment. The interobserver agreement was calculated using the weighted Cohen's Kappa.

RESULTS: Normal carpal joints ($n = 9$) were investigated. MRA improved visualization of the majority of carpal ligaments compared to MRI ($p < .05$) and offered the best visualization overall. MRI and MRA offered a better visualization than both CT and CTA ($p < .05$). There was no significant difference between CT and CTA. Interobserver agreement was discrete ($0.2 < \text{Kappa} \leq 0.4$) for all observers.

CONCLUSIONS: Arthrography improved the capabilities of MRI, but not of CT, for visualization of the canine carpal ligaments. MRA was particularly useful for evaluation of the stabilizers of the antebrachiocarpal joint.

CLINICAL SIGNIFICANCE: 3 Tesla MRA and MRI allow excellent visualization of the ligamentous morphology and may be helpful in the diagnostic process of carpal sprains in dogs.

INTRODUCTION

Sprain injuries of the carpal ligaments are frequently encountered in dogs and can lead to severe lameness and functional disability.[1] Carpal sprains are sustained under a variety of circumstances, such as slipping and sliding on a floor, falling or jumping from a height, or tumbling over an obstacle.[2] Working dogs which are exposed to repeated and sustained exercise are prone to carpal sprains.[3] Damage to the palmar structures leads to carpal hyperextension, which is the most common type of carpal injury in the dog.[4]

The evaluation of the sprained carpus poses a diagnostic challenge given the small size and large number of ligaments that stabilize the joints. Orthopedic and radiographic examinations are the mainstay of the diagnostic process, and are sufficient in most of the cases to achieve an accurate diagnosis.[5,6] However, some patients suffer from long-lasting pain and reduced carpal function due to diagnosis oversight, followed by inappropriate treatments.[7] Stressed radiographs aid to better determine the level of instability,[8] but especially in cases of mild or moderate sprains, they may not adequately portray spatial derangement of the individual joint levels.[7] In people advanced imaging modalities such as Magnetic Resonance Arthrography (MRA) and Computed Tomography Arthrography (CTA) are routinely used to identify ligament tears when radiographs are normal.[9] Arthrography adds to the capabilities of conventional CT and MRI by distending the joint capsule, identifying contrast solution leakages, and ligament tears of the human wrist. While previous studies have shown that MRI is a feasible imaging modality not only for research but also for clinical use in case of carpal pathology in dogs,[10-13] to the authors knowledge there are no studies that reported the use of CTA and high-field 3 Tesla MRA in the evaluation of the carpal ligaments of the dog. The aim of this study was (1) to evaluate if the addition of intraarticular contrast medium increases the visualization of normal canine carpal ligaments compared to conventional CT and MRI techniques; (2) to evaluate which imaging technique offers the best visualization of the ligaments overall; and (3) to determine the interobserver agreement. We hypothesized (1) that CTA and MRA would provide a better visualization than CT and MRI, respectively, and; (2) that MRA would provide the best visualization overall.

MATERIALS AND METHODS

Specimens

Unpaired normal thoracic (n = 9) limbs were obtained with owner permission from skeletally mature dogs weighing over 20 kg that were euthanized for reasons unrelated to the study. No clinical data relating to those animals were available. Specimens were collected according to our institution regulation. Carpal joints without gross pathological findings on orthopedic examination were included. The exclusion criterion was the presence of ligament abnormalities or osteoarthritis in CT or MRI. Limbs were transected at the level of the distal humerus and frozen at - 20°C until the imaging study. Limbs were thawed to room temperature for 24 hours and the carpal region was clipped circumferentially prior to imaging. In order to acquire images in a similar angulation (180°) throughout all imaging studies, limbs were mounted and held in position with tie wraps on a custom-made wooden stabilization device (Figure 1).

Imaging

Contiguous 0.8 mm thick slices were acquired using a 16-slice CT scanner (Philips 16 Brilliance, Philips AG, Zurich, Switzerland) from the distal radial metaphysis to the proximal metacarpal metaphyses in medium and high frequency reconstruction algorithms. The CT settings used were: 250 mA, 130 kVp with a rotation time of 1 second. An acquisition matrix of 1024x1024 was used. The field of view (FOV) was adjusted to the dimensions of the specimens. Multiplanar reconstructions of the carpus were generated in transverse, sagittal, and dorsal planes.

MRI and MRA images were obtained using a 3.0 Tesla magnet (Philips Ingenia, Philips AG, Zurich, Switzerland) and a surface coil Micro-47 (Philips Medical Systems, Best, The Netherlands). Due to limb fixation maintained using the wooden device, the limb positioning was equivalent to that of the CT imaging. Dependent on the size of the specimen, the FOV was adjusted and 1 mm contiguous slices were acquired. Alignment of the transverse, sagittal, and dorsal scan planes equaled CT image acquisition. MRI scanning parameters are summarized in Table 1.

After CT and MRI images had been acquired, a diluted contrast mixture containing iohexol and gadodiamide was injected with a 22-gauge needle from a dorsal approach into the middle carpal joint and then into the radiocarpal joint under fluoroscopy control (Allura Xper FD20 Biplane, Philips). Contrast medium concentration was based on human reference values,[14] and the final solution contained 175mgI/ml iohexol (Accupaque 350, GE Healthcare Buchler GmbH & Co. KG, München, Germany) and 1:200 gadolinium:solution ratio (Omniscan 0.5 mmol/ml, GE Healthcare). Aspiration of synovial fluid before contrast injection, flow of contrast medium away from the needle tip, and opacification of the joint spaces on the palmar side confirmed adequate intra-articular contrast administration. Contrast injection was discontinued as soon as palpable resistance was sensed during pressure on the syringe plunger or contrast backflow was identified on fluoroscopy.

Subsequent to contrast injection, CTA and MRA images were acquired using the same imaging protocol for CT as well as T1 weighted sequences for MRI.

Anatomic preparation

After completion of CT, MRI, CTA and MRA image acquisition, the extremities were frozen at - 80°C while still mounted on the fixation device for at least 24 h. The frozen joints were sliced into 2 mm thick sections in dorsal (3 specimens), sagittal (3 specimens), and transverse planes (3 specimens) using an electric band saw. Sliced anatomic specimens were digitally scanned (Epson Perfection V700 Photo Scanner, Epson Deutschland GmbH, Kloten, Switzerland).

Images analysis

CT, MRI, CTA, and MRA images were evaluated by three independent observers with different levels of training, including two board-certified radiologists, and a first-year surgical resident. Images were viewed using an open source imaging software (Osirix version 3.9.4, 32-bit, Pixmeo, Geneva, Switzerland). Observers were permitted to alter the scan plane, the window level and width, and the zoom within the individual imaging study. Anatomic slices were available as anatomic reference for the observers during the analysis of the digital images.

For each imaging modality the observers identified and scored selected carpal ligaments and soft tissue structures of clinical interest (Table 2). The visibility of the ligaments was graded on an integer numeric scale with scores from 0 to 4 (no (0), poor (1), satisfactory (2), good (3), and excellent (4) visualization).

Statistical Analysis

The frequency of the visualization score for each individual ligament in CT, MRI, CTA, and MRA was calculated to describe the performance of each of the four imaging modalities. A random effect ordinal logistic regression was applied to evaluate the difference between imaging modalities. Two random effects were considered, the observers and the specimens, assuming that observations within observers and specimens were clustered and therefore more similar than between observers and specimens. The model estimated the probability of having low visualization scores by comparing each score level with the higher ones (0 vs 1,2,3,4; 0,1 vs 2,3,4 and so on). The analyses were performed considering all the structures together (pooled data) and each individual anatomical structure for all the imaging modalities. Given the large number of tests performed, the Bonferroni adjustment was applied to take into account the problem of multiplicity. P values $< .05$ were considered significant. The interobserver agreement was calculated between pairs of observers using the weighted Cohen's Kappa, where the discordances between adjoining categories (e.g. observer 1 = score 3, observer 2 = score 4) had a smaller weight than distances between distant categories (e.g. observer 1 = score 0, observer 2 = score 4). According to the scale of Landis and Koch, the agreement was classified as: no agreement ($0 \le k$), poor ($0 < k \le 0.2$), discrete ($0.2 < k \le 0.4$), moderate ($0.4 < k \le 0.6$), good ($0.6 < k \le 0.8$), great ($0.8 < k \le 1.0$).

RESULTS

Arthrography

Depending on the size of the specimen, arthrography was performed using 1 to 3 ml of contrast solution injected into the radiocarpal joint and 1 to 2 ml of contrast solution into the middle carpal joint. Communication between the radiocarpal and middle carpal joint was absent in all specimens. Opacification of the joint spaces on the palmar side confirmed adequate contrast administration into the middle carpal joint. Opacification of the dorsal and palmar capsular recesses confirmed adequate contrast administration into the radiocarpal joint (Figure 2). Mild extravasation of contrast material outside the joints along the needle tract occurred in some specimens, possibly as a result of overdistention of the joint, but did not interfere with the evaluation of the images.

Comparison of techniques considering all the ligaments together (pooled data)

The frequencies of the visualization scores according to the imaging technique on the overall sample are presented in Figure 3. MRA had the highest frequency of score 4 (45%) compared to the other imaging techniques, and had a lower frequency of score 0 (3.4%) and 1 (8%) compared to MRI (score 0 = 6.1%; score 1 = 12.5%). MRI had a higher frequency of score 3 (30%) and 4 (34%) compared to both CTA (score 3 = 21%; score 4 = 2.1%) and CT (score 3 = 21.6%; score 4 = 3.2%).

The results of the regression analysis are presented in Table 3. MRA demonstrated a better visualization of the ligaments compared to MRI ($p < .05$). MRI and MRA offered a better visualization compared to both CT and CTA ($p < .05$). There was no difference between CT and CTA.

Comparison of techniques considering each individual ligament

The frequencies of the visualization scores according to the imaging technique for each individual ligament are presented in Figure 4. For all anatomical structures the frequency of score 3 or 4 were higher for MRI and MRA compared to CT and CTA. No strong differences were observed between CT and CTA. Conversely, for several anatomical structures such as the palmar radiocarpal and ulnocarpal ligaments, the frequency of score 4 were higher in MRA than MRI.

The results of the regression analysis are presented in Table 4. MRA significantly improved the visualization of all ligaments compared to MRI ($p < .05$), excluding the dorsal radiocarpal ligament, the lateral accessoriometacarpal ligament, the medial accessoriometacarpal ligament, and the palmar fibrocartilage, where no difference was found. Regarding CT and CTA, no differences were found in any anatomical structures.

Representative images that show the difference between CT, CTA, MRI, and MRA are presented (Figures 5,6,7).

Interobserver agreement

The interobserver agreement was discrete for all observers, with weighted Kappa = 0.3079 for radiologist number 1 vs surgery resident comparison; weighted Kappa = 0.2574 for radiologist number 2 vs surgery resident comparison; and weighted Kappa = 0.2874 for radiologist number 1 vs radiologist number 2 comparison.

DISCUSSION

This is the first study that describes the use of CTA and 3 Tesla MRA in the evaluation of the carpal ligaments of the dog. Our results suggest that MRA is superior to MRI, CTA and CT in the visualization of the intact carpal ligaments of dogs weighing more than 20 kg. MRA was particularly useful in the evaluation of the stabilizers of the antebrachiocarpal joint, such as the palmar ulnocarpal and radiocarpal ligaments, the radioulnar ligament, and the medial and lateral collateral ligaments. Contrast medium introduction increased intraarticular pressure and joint capsule distension, allowing easier recognition of the edges of the collateral ligaments, as well as surrounding the intraarticular palmar ulnocarpal and radiocarpal ligaments. Furthermore, the presence of contrast medium intensified the contrast-to-noise ratio, offering a better visualization also for some extra-articular structures such as the tendon of the musculus flexor carpi ulnaris. These findings are in agreement with previous studies that described the benefits of MRA in the visualization of intraarticular structures, such as the cruciate ligaments of the stifle joint,[15-16] and the biceps tendon of the shoulder joint in dogs.[17] Conversely, these finding are in contrast to published literature in human medicine, where CTA is considered as accurate or even more accurate than conventional 3 Tesla MRI for detecting tears of the intrinsic ligaments, such as the scapholunate and lunotriquetral ligaments.[18] Tears of these ligaments typically manifest in CTA with contrast filling of the defect and abnormal communication between the different joint compartments. Further studies may evaluate if the diagnostic value of CTA may be improved in cases of tears of the intercarpal ligaments in dogs.

Due to its high contrast resolution, high-field 3 Tesla MRI facilitated excellent visualization of the ligamentous morphology. For some anatomic structures such as the lateral and medial accessoriometacarpal ligaments and palmar carpal fibrocartilage, MRA did not provide a better visualization compared to MRI. The accessoriometacarpal ligaments and the palmar fibrocartilage are major contributors to prevention of carpal hyperextension,[19] which is the most common type of carpal injury in the dog. These large extra-articular structures could be clearly and consistently identified in MRI, suggesting that the major palmar stabilizers of the carpus can be characterized with MRI without arthrography.

CTA showed poor soft tissue contrast resolution, allowing only indirect recognition of the edges of the ligaments and did not result in a significantly better visualization compared to CT. This is in contrast to previous studies that have reported an improved visibility of intraarticular ligaments of the canine stifle and shoulder joints with CTA.[20-21] A possible explanation could be the smaller joint dimension and tightness of the carpus compared to bigger joints, and the associated inherent difficulties of joint distension of the carpal joint. Furthermore, only few carpal ligaments are fully intraarticular, while the cruciate ligaments of the stifle and the biceps tendon of the shoulder are contained within the joint, allowing better contrast distribution around these structures.

CT has an inherent poor soft tissue contrast resolution compared to MRI, but we included the CT data in the analysis in order to compare pre- and post arthrography CT studies and to determine if CTA could improve the identification of the canine carpal ligaments.

There are several limitations to this study. First, the high-field strength of the 3 Tesla MRI machine may have affected the comparison between the different imaging techniques. Inclusion of a low-field MRI in the study could have helped to determine the impact of the magnetic field strength on the results. However, one of the purposes was to test if addition of intraarticular contrast could increase the visualization of ligaments compared to conventional CT and MRI. This evaluation was independent from the field-strength of the MRI machine and did not affect the results of the comparison between the conventional techniques and the arthrography techniques.

Second, the qualitative assessment performed by visual evaluation and scoring of the ligaments may have been susceptible to inaccuracy due to subjective perspective of the observers. A quantitative assessment by measuring relative signal intensity and relative contrast of the ligaments on digital images has been described,[22] and could have been a more objective methodology. However, the clinical and practical utility of the individual imaging modality was questioned and as such the qualitative assessment of the observers was investigated.

Third, we found only a discrete ($0.2 < \text{Kappa} \leq 0.4$) interobserver agreement. Since our study was the first one to assess the carpal ligaments with MRA and CTA, we decided to determine the interobserver agreement and include at least two board-certified radiologists to minimize the degree of subjective interpretation. The lack of previous studies and limited experience with arthrography of the carpus likely affected the interobserver agreement. In support to this assumption, the interobserver agreement between the two board-certified radiologist was not substantially different compared to the interobserver agreement between the surgery resident and each board-certified radiologist. The choice to include one resident in the analysis was driven by the consideration that evaluation of diagnostic images is performed frequently by observers with different level of experience, including residents. Further training and experience with the arthrography technique may improve identification of the ligaments and interobserver agreement.

Another limitation of the study is that the volume of contrast medium and injection pressure was not standardized among specimens. This variability may have affected the results, with insufficient or excessive contrast medium decreasing the value of MRA and CTA due to inadequate contrast distribution or artefacts due to extra-articular contrast leakage artefacts. However, contrast injection was performed using manual pressure control by the same operator and appropriate joint filling was confirmed with fluoroscopy. The type of contrast medium was chosen based on recommendations available for people and effects of varying volumes and concentrations of contrast medium were beyond the scope of this study.

Finally, a limitation of this study is represented by its ex-vivo nature. Freezing and thawing of the specimens and specimen variability may have affected the quality of visualization of the ligaments and the results of the study. Further investigations conducted on a more homogeneous in-vivo population would be advantageous. The use of cadaveric specimens could also have affected the capacity of joint distension and subsequently the volume of contrast medium injected, which may be altered in dogs with carpal pathology and joint effusion. Joint effusion may yield an "arthrogram-like" effect in T2 sequences, sufficient to eliminate the need for intraarticular contrast in a clinical scenario. Furthermore, the cadaveric study design prevented assessment of the impact of intravenous administration of contrast medium, which could show changes in signal intensity and have great diagnostic value in a clinical scenario.

In summary, this study supports the use of high-field 3 Tesla MRI and MRA for visualization of the canine carpal ligaments. MRA improved significantly the visualization of the majority of ligaments, and was particularly useful in the evaluation of the stabilizers of the antebrachiocarpal joint, while the major palmar stabilizers of the carpus could be identified in MRI without arthrography. These techniques may be useful for identification of specific ligament injuries and for guiding treatment selection in canine patients, such as selecting candidates for ligament reconstruction and for partial or pancarpal arthrodesis. However, the usefulness of these techniques has first to be validated in clinical patients where other factors such as joint effusion, joint fibrosis and osteoarthrosis may affect visibility of the ligamentous structures.

DISCLOSURE

None of the listed authors have a financial interest in any of the products or companies described in this manuscript.

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FIGURE LEGENDS

Figure 1. A custom-made wooden stabilization device was used to hold the limbs in the same position throughout the imaging study.

Figure 2. Fluoroscopic images, lateral view. A, Contrast is injected with a 22-gauge needle from a dorsal approach into the middle carpal joint. B, Opacification of the joint spaces on the palmar side confirms adequate contrast administration into the middle carpal joint (arrowhead). Please note the absence of communication between the radiocarpal and middle carpal joint. C, Contrast is injected into the radiocarpal joint. D, Opacification of the dorsal and palmar capsular recesses confirms adequate contrast administration into the radiocarpal joint (arrowheads).

Figure 3. Graphic illustrating the frequencies of the visualization scores according to the imaging technique on the overall sample (pooled data).

Figure 4. Graphics illustrating the frequencies of the visualization scores according to the imaging technique for each individual ligament.

Figure 5. Transverse section of the canine carpus. The medial aspect of the joint is on the right of the images, and dorsal is at the top of the images. A, T1W MRI; B,T1W MRA; C, frozen anatomic section; D, T2W MRI; E, PDW MRI with fat saturation. The delineation of the intraarticular ligaments such as the palmar ulnocarpal (PUCL) and the palmar radiocarpal ligament (PRCL) in MRI depends on the signal characteristics of the

ligaments and the synovial fluid, and is low in T1W MRI (Figure 5A) compared to T2W or PDW MRI images (Figure 5D,E). Please note how arthrography facilitates recognition of intraarticular ligaments by altering the signal characteristics and distension of the joint (Figure 5B). R, radius; U, ulna; MECR, musculus extensor carpi radialis tendon; MAPL, musculus abductor pollicis longus tendon; oMCL, oblique part of the medial collateral ligament; MFCR, musculus flexor carpi radialis tendon; MFDP, musculus flexor digitalis profundus tendon; MFDS, musculus flexor digitalis superficialis tendon; MFCU, musculus flexor carpi ulnaris tendon; PRCL, palmar radiocarpal ligament; PUCL, palmar ulnocarpal ligament; MECU, musculus extensor carpi ulnaris tendon; RUL, radioulnar ligament; MEDL, musculus extensor digitalis lateralis; MEDC, musculus extensor digitalis communis tendon.

Figure 6. Dorsal section of the canine carpus. The medial aspect of the joint is to the left of the images, and proximal is at the top of the images. A, T1W MRI; B, T1W MRA; C, frozen anatomic section; D, CT; E, CTA. Intraarticular contrast medium improved delineation of the margins of the oblique part of the medial collateral ligament (oMCL) and radioulnar ligament (RUL) in MRA (Figure 6B) compared to T1W MRI (Figure 6A). CT and CTA images are presented (Figure 6D,E) in soft tissue reconstruction with soft tissue windowing, optimized for delineation of ligamentous structures (WL/WW: 45/180). CT and CTA did not allow separation of the different components of the medial collateral ligament, and delineation of the radioulnar ligament (RUL) was poor in both CT and CTA. R, radius; RCB, radial carpal bone; UCB, ulnar carpal bone; CII, second carpal bone; CIII, third carpal bone; CIV, fourth carpal bone; RUL, radioulnar ligament;

ICL, intercarpal ligament; oMCL, oblique part of medial collateral ligament; MAPL, musculus abductor pollicis longus tendon.

Figure 7. Sagittal section of the canine carpus. The dorsal aspect of the joint is to the left of the images, and proximal is at the top of the images. A, T1W MRI; B, T1W MRA; C, frozen anatomic section; D, T2W MRI; E, PDW MRI with fat saturation. Please note how contrast medium allows improved delineation of the intraarticular structures, such as the dorsal radiocarpal ligament (DRCL), the palmar radiocarpal (PRCL), and palmar ulnocarpal ligaments (PUCL) in MRA (Figure 7B) compared to MRI (Figure 7A) due to joint distension. Extra-articular structures such as the medial accessoriometacarpal ligament (MACBL) are clearly visible in MRI, regardless of the MRI sequence and contrast administration. R, radius; UCB, ulnar carpal bone; ACB, accessory carpal bone; CIV, fourth carpal bone; DRCL, dorsal radiocarpal ligament; MFCU, musculus flexor carpi ulnaris tendon; AUCL, accessorioulnocarpal ligament; MACBL, medial accessoriometacarpal ligament; PRCL, palmar radiocarpal ligament; PUCL, palmar ulnocarpal ligament.

TABLES

Table 1. Summary of MRI scanning parameters used in the study.

Parameters	T2W TSE			PDW FS			T1W		
Plane	sag	dor	trans	sag	dor	trans	sag	dor	trans
ST (mm)	1	1	1	1	1	1	1	1	1
Matrix	228x172	280x272	200x169	400x236	400x234	300x144	320x168	320x170	200x165
TR (ms)	2723	3251	5990	3088	3070	5526	632	742	739
TE (ms)	80	80	80	30	30	30	11	11	11
IG (mm)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
NSA	5	3	4	2	4	4	4	6	4
FA (degree)	90	90	90	90	90	90	90	90	90

ST, slice thickness; TR, repetition time; TE, echo time; IG, interslice gap; NSA, number of signal averages; FA, flip angle; T2W TSE, T2-weighted turbo spin echo; PDW FS, proton density-weighted fat saturated; T1W, T1 weighted.

Table 2. Ligaments and soft tissue structures selected for the investigation and relative abbreviations.

1. Dorsal radiocarpal ligament (DRCL)
2. Insertion of the M. extensor carpi ulnaris tendon (MECU)
3. Insertion of the M. flexor carpi ulnaris tendon (MFCU)
4. Lateral accessoriometacarpal ligament (LACBL)
5. Lateral collateral ligament (LCL)
6. Accessorioulnocarpal ligament (AUCL)
7. Medial accessoriometacarpal ligament (MACBL)
8. Oblique part of the short medial collateral ligament (oMCL)
9. Straight part of the short medial collateral ligament (sMCL)
10. Palmar radiocarpal ligament (PRCL)
11. Palmar ulnocarpal ligament (PUCL)
12. Palmar carpal fibrocartilage (PCFC)
13. Radiocarpal-metacarpal ligament (RCML)
14. Radioulnar ligament (RUL)

Table 3. The estimate (beta), the corresponding standard error (S.E.) and the Bonferroni adjusted p value on the overall sample. A negative estimate implies that the first technique leads to a better visualization compared to the second technique. $P < .05$ is significant.

Technique	beta	S.E.	p value
CT vs. CTA	-0.05053	0.1289	1
CT vs. MRA	7.7198	0.3398	<.0001
CT vs. MRI	17.8338	0.9013	<.0001
CTA vs. MRA	7.8714	0.3395	<.0001
CTA vs. MRI	18.2886	0.9003	<.0001
MRA vs. MRI	-5.3256	0.6074	<.0001

Table 4. The estimate (beta), the corresponding standard error (S.E.) and the Bonferroni adjusted p value for the single structures. A negative estimate implies that the first technique leads to a better visualization compared to the second technique. $P < .05$ is significant.

Anatomical Structure	MRA vs MRI			CTA vs CT		
	beta	S.E.	p value	beta	S.E.	p value
DRCL	-4.7	2.1	0.05	0.1	0.5	1
MECU	-10.3	3.4	<.05	0.2	0.4	1
MFCU	-6.8	2.3	<.05	-0.2	0.4	1
LACBL	3.4	2.8	0.4	0.3	0.5	1
LCL	-5.5	2.4	<.05	0.3	0.4	0.9
AUCL	-9.8	2.2	<.05	0.01	0.6	1
MACBL	5.1	2.6	0.1	0.09	0.5	1
oMCL	-10.4	0.3	<.05	0.4	0.7	1
sMCL	-5.9	2.2	<.05	0.3	0.5	0.8
PRCL	-14.7	2.3	<.05	-0.9	0.4	0.1
PUCL	-23.5	3.0	<.05	0.02	0.5	1
PCFC	-1.6	2.2	0.9	0.07	0.5	1
RCMCL	-11.0	4.0	<.05	0.7	0.5	0.3
RUL	-8.8	2.4	<.05	-0.5	0.5	0.6